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THE CAVEMAN CAVERN PRESSURIZATION MODEL

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15p.

INTRODUCTION

- CAVEMAN predicts the cavern pressurization rate which results from cavern volume reduction due to salt creep and thermal expansion of fluids in the cavern.
- CAVEMAN is a semi-empirical salt mechanics and thermal model that uses historical measured cavern pressures and temperatures to derive the mechanical and thermal properties of the salt/fluid system which result in the most accurate match between measured and predicted cavern pressures.
- CAVEMAN can be used to predict present and future cavern pressures and hence can be used by cavern engineers to quantitatively assess measured cavern pressures.
- The goal is to detect cavern leaks in 'real time' and, perhaps some day, to modify the current cavern re-certification process to require Cavern Integrity Tests only on an as-needed basis.

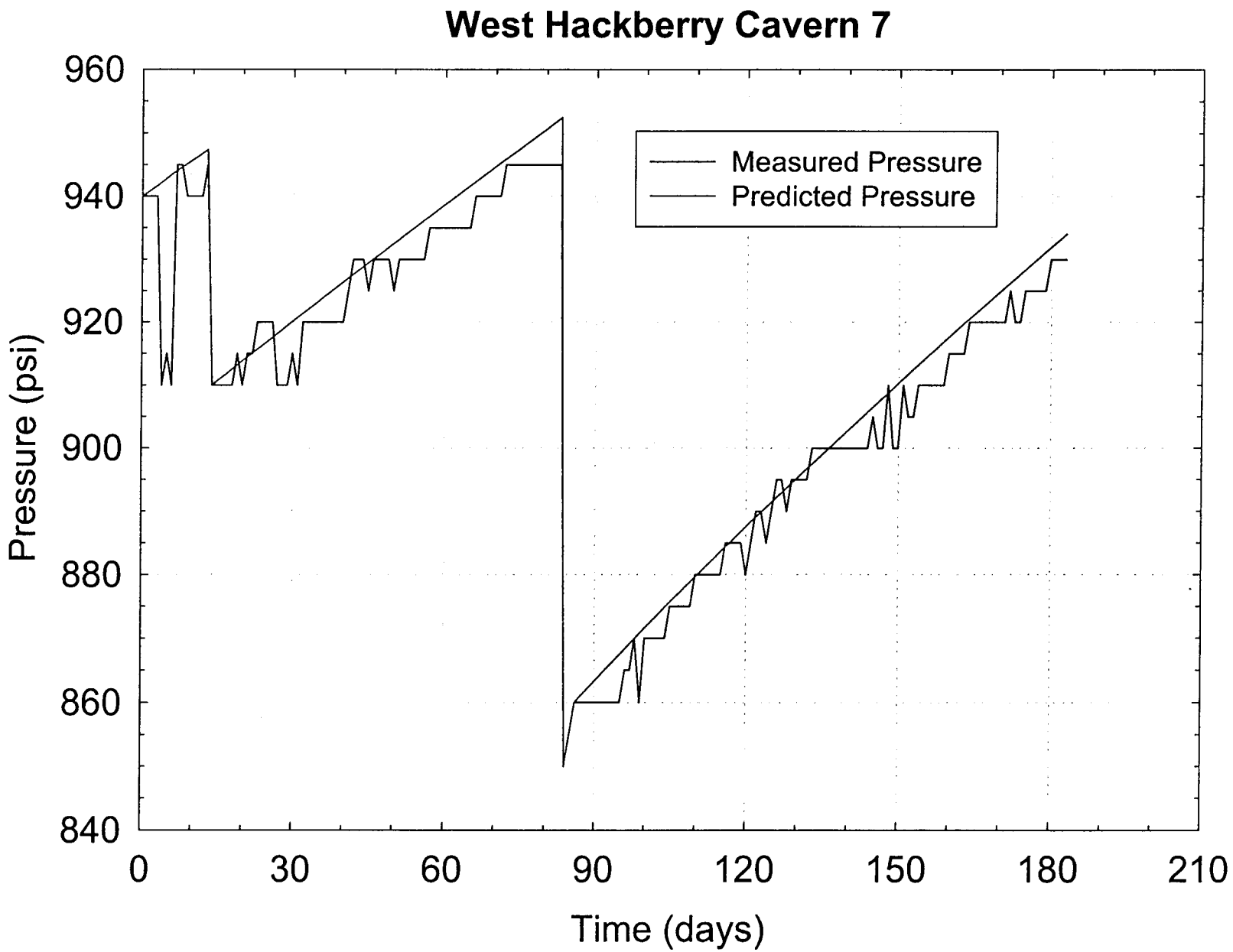
IMPLEMENTATION

- To be useful, the model has been implemented in such a way that:

  it places minimum additional burden on the people responsible for reporting cavern status

  the model results are easily interpretable

- To achieve these goals, the model was incorporated into the Excel-based daily reporting system already in use, resulting in only a trivial increased burden on the cavern engineer.
- Cavern pressure status is reported in 2 forms. A cavern pressure "Status Variable" is automatically reported on the cavern daily report form in High/OK/Low format. Powerful data analysis tools are also available to the cavern engineer should the need arise.


West Hackberry Cavern 7
960
940
920
900
880
860
840
Pressure (psi)
0
30
60
90
120
150
180
210
Time (days)
Measured Pressure
Predicted Pressure

PRESSURE INCREASE RATIO

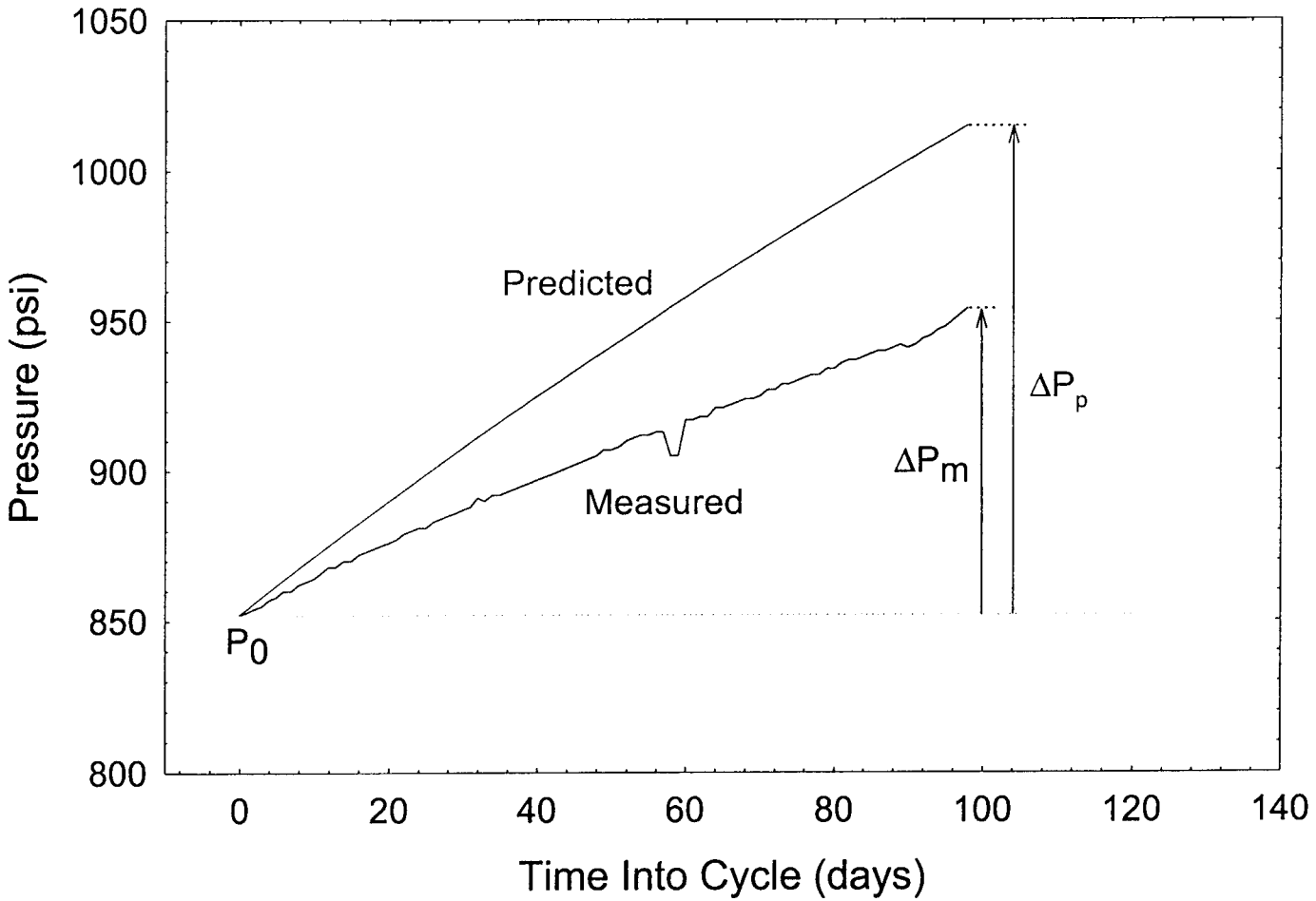
Since CaveMan predicts pressurization rate, it is desirable to compare the measured and predicted pressurization rates, $dP_{measured}/dt$ and $dP_{predicted}/dt$, rather than the absolute pressures. The ratio of these two pressurization rates is expected to be close to 1:

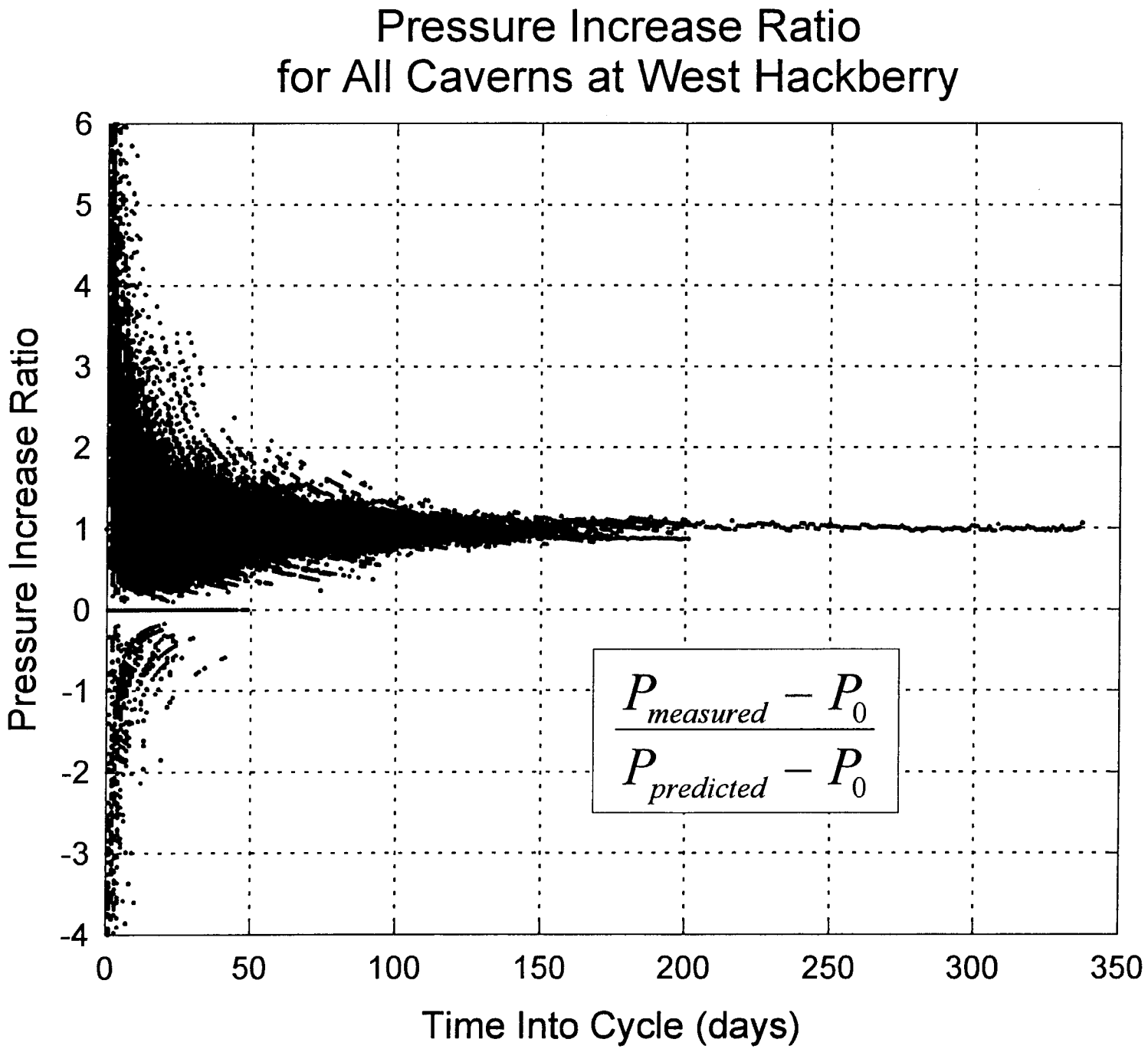
$$\frac{\partial P_{measured}/dt}{\partial P_{predicted}/dt} = \frac{\Delta P_{measured}}{\Delta P_{predicted}} \approx 1$$

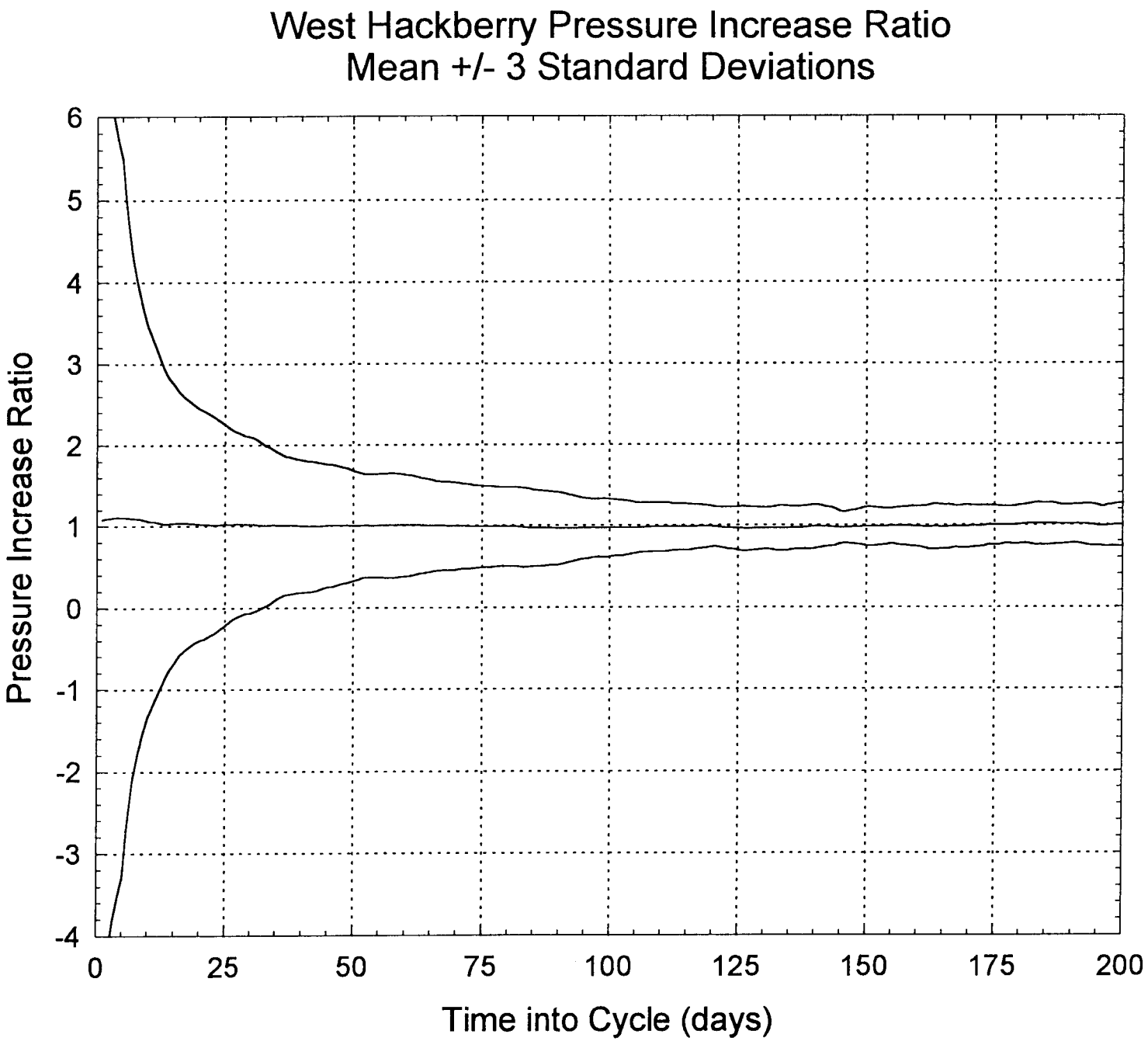
Because the resolution of the measured pressures is quite large (about 5 psi) compared to typical predicted daily pressure increases (typically 1 to 2 psi/day), comparing measured and predicted daily pressure changes yields poor results. It is preferable to compare the changes in measured and predicted pressures since the beginning of the current cycle (predicted pressure is equated to the measured pressure at the start of a cycle).

$$PIR = \frac{P_{measured} - P_0}{P_{predicted} - P_0} \approx 1$$

This value is called the **Pressure Increase Ratio (PIR).**


1050
1000
950
900
850
800
Pressure (psi)
0
20
40
60
80
100
120
140
Time Into Cycle (days)
Predicted
Measured
ΔP_p
ΔP_m
P_0


Pressure Increase Ratio
for All Caverns at West Hackberry
Pressure Increase Ratio
Time Into Cycle (days)
6
5
4
3
2
1
0
-1
-2
-3
-4
0
50
100
150
200
250
300
350
$\frac{P_{measured} - P_0}{P_{predicted} - P_0}$


West Hackberry Pressure Increase Ratio
Mean +/- 3 Standard Deviations
Pressure Increase Ratio
6
5
4
3
2
1
0
-1
-2
-3
-4
0
25
50
75
100
125
150
175
200
Time into Cycle (days)

CAVERN PRESSURE STATUS VARIABLE

For every cavern pressure measurement made at a time when the cavern pressure is not being manipulated by injecting or extracting fluids from the cavern, a PIR value can be calculated. From historical data collected during times when the cavern appeared to be behaving 'normally', the mean and standard deviation of the Pressure Increase Ratio as a function the number of days into a pressure cycle can also be calculated.

We define the **Cavern Pressure Status Variable** as

$$\text{StatusVariable} = \frac{\left(PIR_i - \overline{PIR}\right)}{3\sigma_{PIR}}$$

If a PIR value falls between the two 3σ lines, the measured and predicted pressures are not significantly different and the Status Variable will be between -1 and 1 (OK). Below the bottom line, the measured pressure is significantly less than the predicted pressure, implying a possible leak, and the Status Variable will be less than -1 (Low). Above the top line, the measured pressure significantly exceeds the predicted pressure, implying accelerated salt creep and potential cavern instability. In this case the Status Variable will exceed 1 (High).

CONCLUSIONS

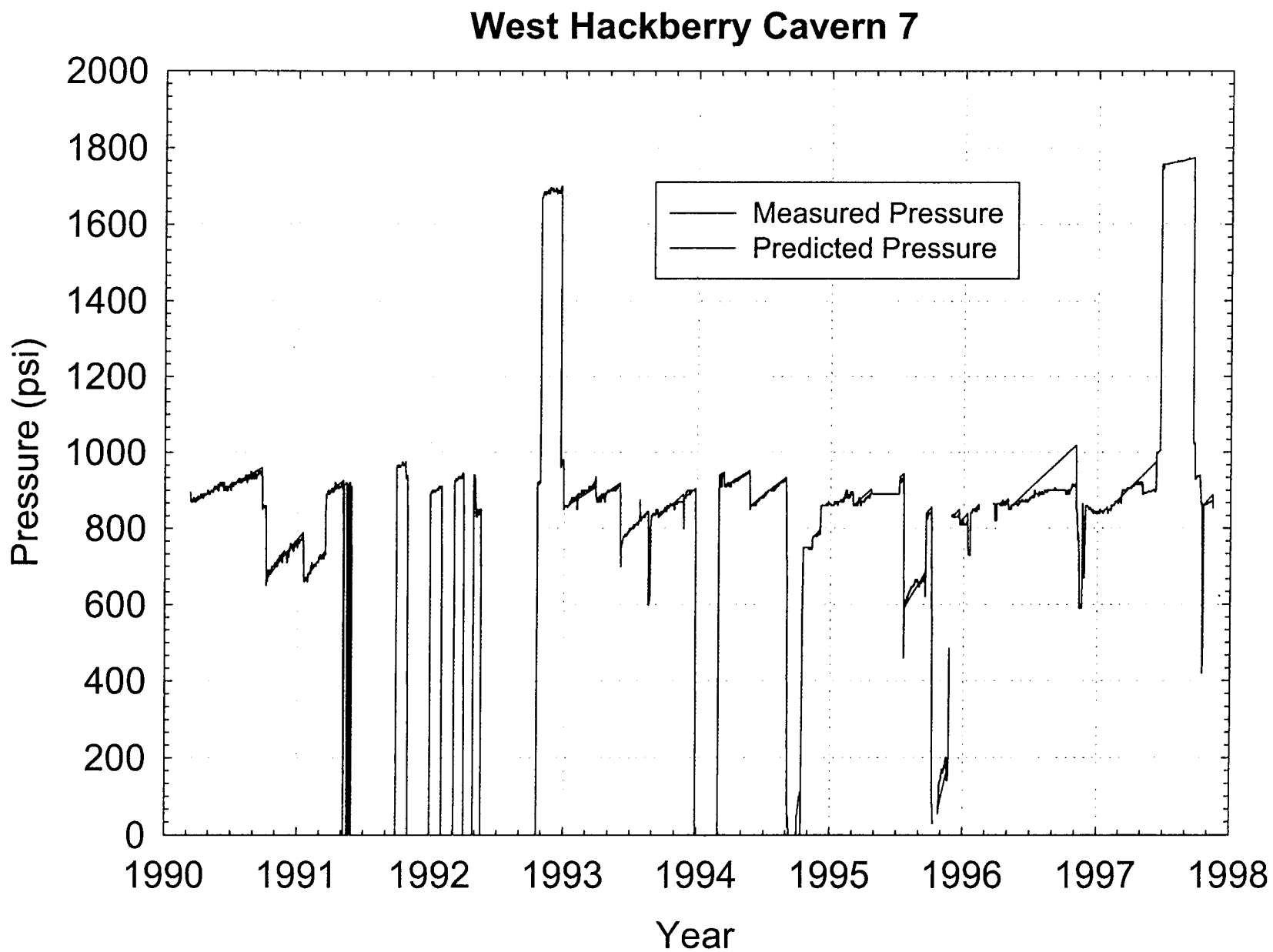
- The new CaveMan model has been incorporated into the existing, Excel-based Daily Reporting system.

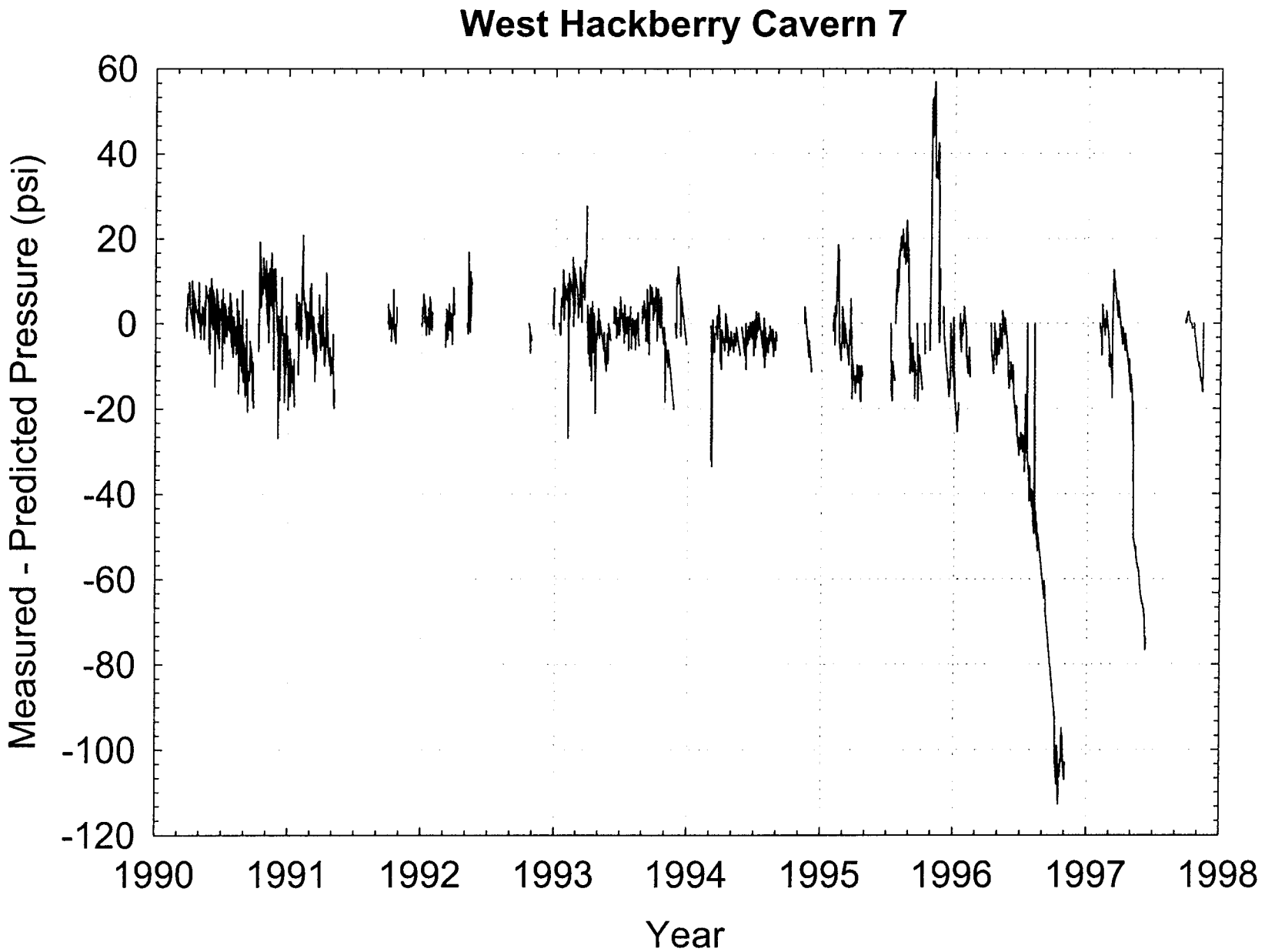
  Minimal burden on site personnel entering data.

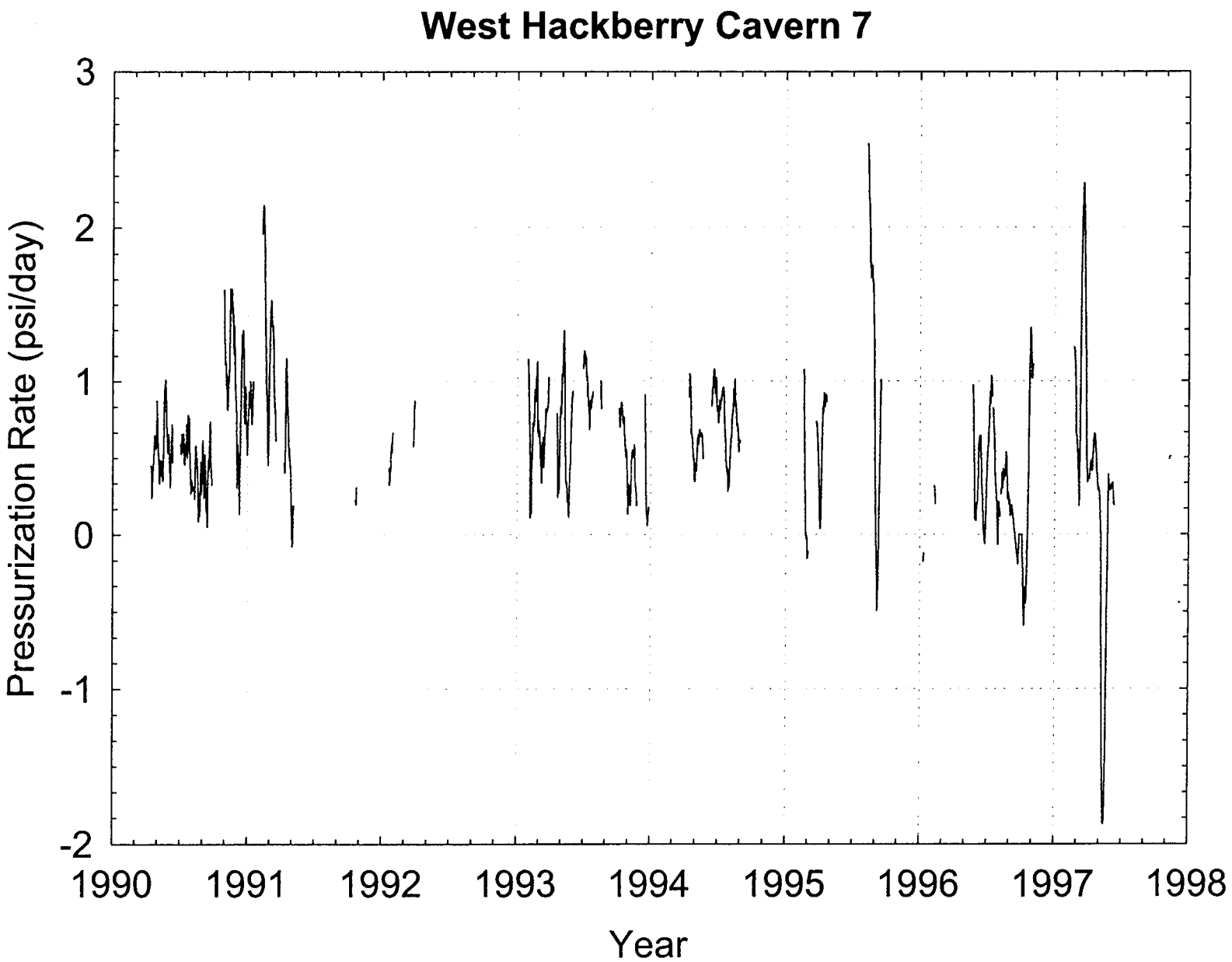
  Model results are easily interpretable and appear automatically on Daily Report.

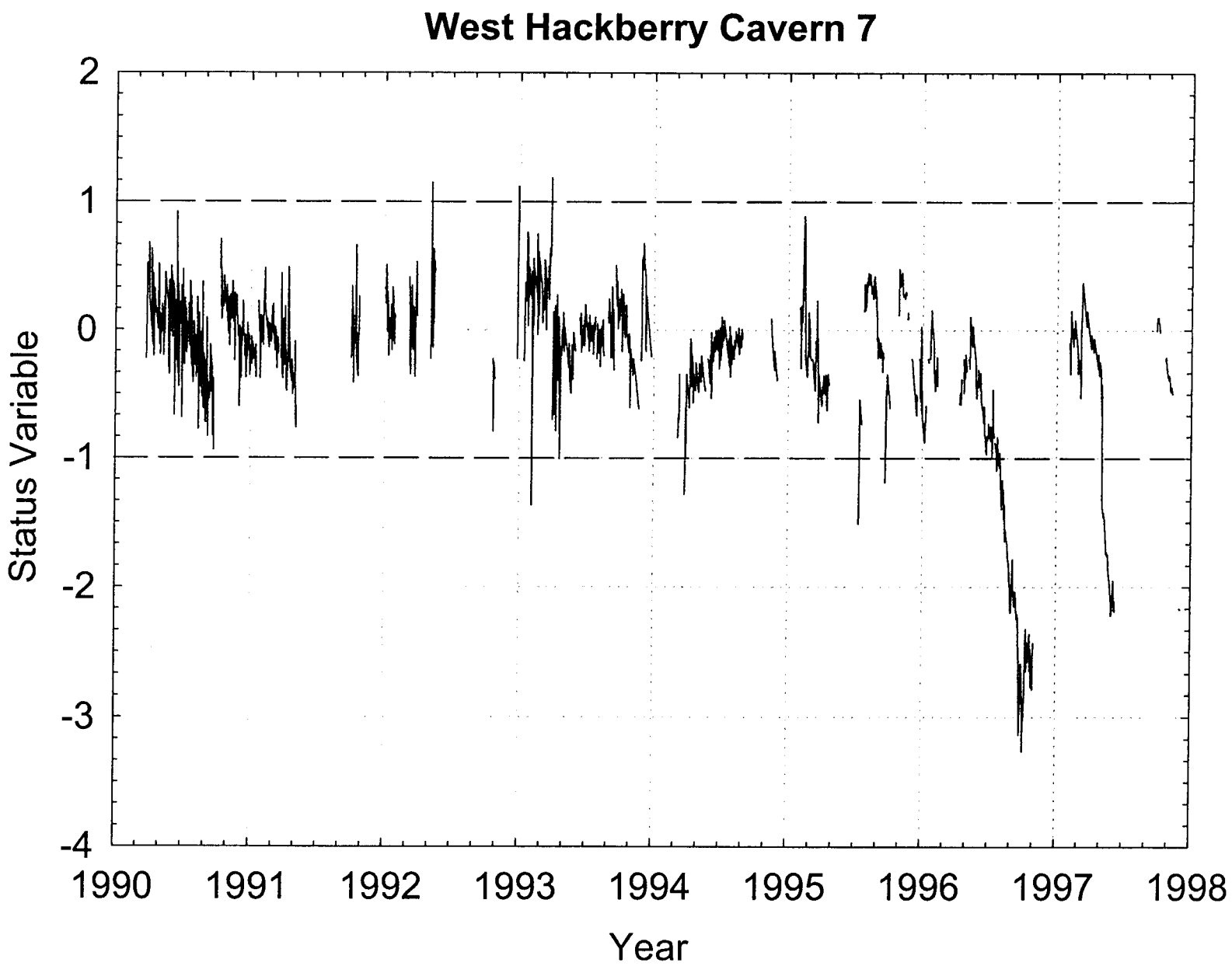
  Includes new software tools (Visual Basic Excel macros) for analyzing cavern pressure data.

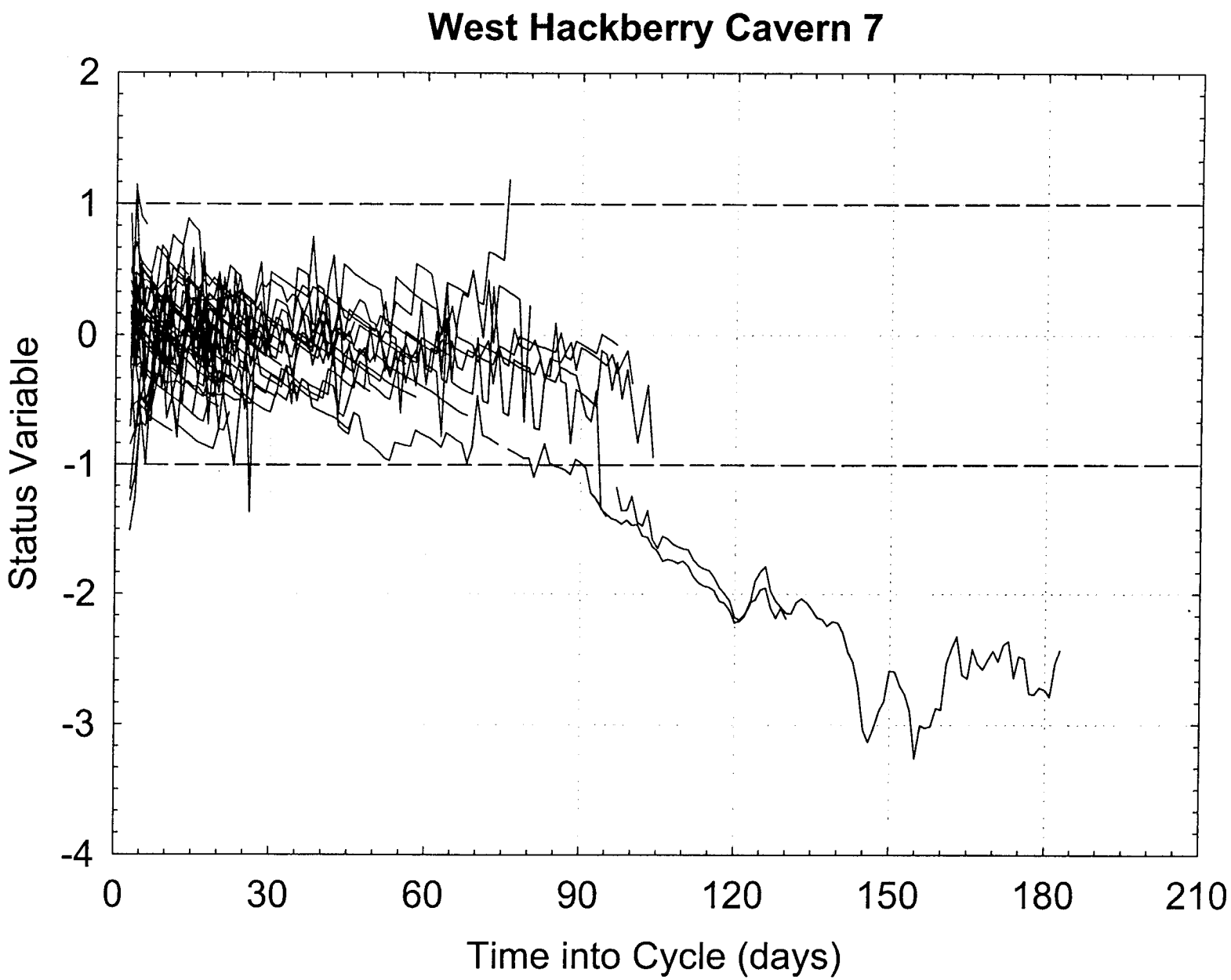
- The new system was installed at West Hackberry in June, 1997 for beta testing. A similar system for Big Hill is almost ready for installation. Other sites will follow soon.


West Hackberry Cavern 7
Measured Pressure
Predicted Pressure
Pressure (psi)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
Year


West Hackberry Cavern 7
Measured - Predicted Pressure (psi)
60
40
20
0
-20
-40
-60
-80
-100
-120
1990
1991
1992
1993
1994
1995
1996
1997
1998
Year


West Hackberry Cavern 7
Pressurization Rate (psi/day)
3
2
1
0
-1
-2
1990
1991
1992
1993
1994
1995
1996
1997
1998
Year


West Hackberry Cavern 7
Status Variable
2
1
0
-1
-2
-3
-4
1990
1991
1992
1993
1994
1995
1996
1997
1998
Year


West Hackberry Cavern 7
Status Variable
2
1
0
-1
-2
-3
-4
0
30
60
90
120
150
180
210
Time into Cycle (days)